A novel approach for closed-loop smart air purifiers using real-time monitored weather data

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***Abstract*—All major air purifiers available in the market work on the principle of open loop system with heavily depending on manual control. Moreover, many significant changes in ambient air quality which they are purifying are neglected or are considered in a very small scale. This paper presents a new approach to monitor and collect the data via various sensors which contribute in determining the quality of air and simultaneously incorporating that data to be fed into the control process of an air purifier mechanism. In this way, manual control of purifiers can be obviated and they can be made "smart" by automatically determining the operating intensity by sensing the surrounding air quality.**

Keywords: Air quality, pollution sensors, air purifiers, closed-loop technique, on-line device operation.

I. INTRODUCTION

Air pollution is arguably the single most important factor affecting the quality of life and well-being of unprecedentedly growing metropolitan populations; countries with developed and developing economies based on hydrocarbons are the one which are worst affected and major contributors to pollution. Apart from the deleterious affects of poor air quality on biodiversity, many technological advances are also hampered due to harmful effects of particles present in the environment. Notably, the presence of dust and air-borne particulate matter affect negatively the efficiency of solar panels used for power generation. In this paper, a comprehensive wireless solution is proposed for monitoring and analyzing the level of pollutants present indoor and outdoor. The system presented proposes the measurement of the proportion of known harmful gases CO2, NO2 CO and CH4 along with dust, temperature, humidity, solar irradiance, pressure, wind-direction and wind speed. Data is collected by appropriate sensors nodes that communicate via Universal Serial Bus port (UART protocol) with a host computer that process, store and display the collected information.

Air filters contains small strainers that segregate particles from circulating air. As air enters the air purifier, the smaller the strainer used, the finer the air particles it encloses within. The universal standard for air filters is determined by the High Efficiency Particulate Air (HEPA) filters, which claims to enclose 99.97% of particles in the air with size larger than 0.3 microns. In contrast, commonly used household air conditioner filters only capture particles 10.0 microns or larger. HEPA filters facilitate in obliterating smaller irritants like dust, smoke, chemicals, asbestos, pollen, and pet dander.

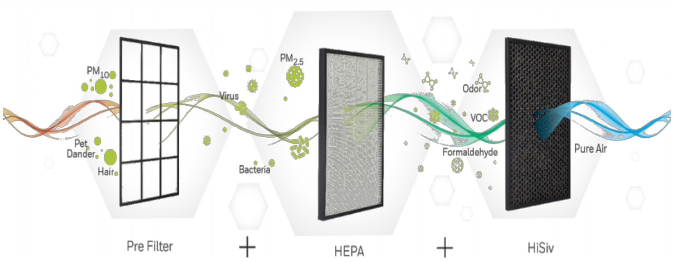

Fig. 1. Air purifying process (HEPA technique)

The major problem with almost all air-purifiers is the underlying open loop mechanism with which they work. If their operation intensity is unchanged by manual control, they continue to work on a constant speed, regardless of the air quality in their surroundings. We propose a mechanism through which their operation can be made automatic and less energy consuming by feeding them the data of ambient air quality in their control mechanism, thereby making the process closed loop.

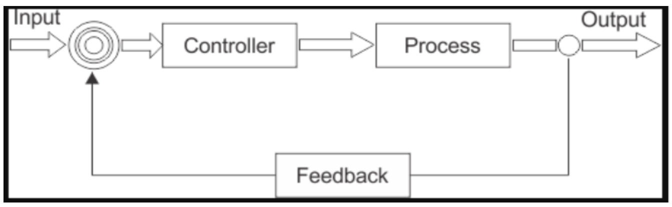

Fig. 2. Closed-loop control process

Due to the exponential increase in the ill-effects of poor air-quality index in population dense areas, namely ill health and premature deaths, as well as damages to ecosystems, crops, and buildings, the requirement of an a low-cost real-time monitoring of air quality is becoming need of the hour to facilitate appropriate and reasonable decisions for public welfare [10] and, ultimately, is quite critical for checking the biodiversity. Additionally, a significant factor of correlation can be found among the gas concentrations and weather variables ([12], [13]). Harnessing this information, we can work to find out the gas variables easily through our apparatus. However, it is often quite a hassle for a common man to monitor the air quality around him. Usually, air quality is monitored by the government through large and expensive sensing apparatus, installed at some remote locations [9], which become an impractical way for citizens to monitor air-quality. Mainly due to this reason, only limited areas are chosen for data gathering and thus general public remains largely oblivious to that. Hence, one of the goals of our study is to investigate whether a low-cost monitoring system can provide reliable information about air quality in a place and, subsequently, can be used in practice. Working on this front, we have obtained pollution measurements obtained by sensors and compared them with the official measurements made available by the local measurement station. In the results of the experiment, it emerges that, even though measurements provided by low-cost sensors are not as accurate as official data, nevertheless they can provide useful information about air quality in a specific location which can be accessed by a common man.

II. Related work

Significant amount of research has been done in the area concerning the deployment of sensors in multiple disciplines. [1] proposes the potential of electromagnetic pollution to provide power supply to micro-devices including wireless sensors in a typical building environment. This can be one of the further challenges for us to implement in our proposed product. A low cost and energy efficient gas sensing modules were successfully developed with improved tolerance to EMF/RFI noise [3]. Also, recalibration of the system at time intervals were defined to ensure that the desired accuracy was maintained. [4] proposes the incorporation of wireless sensor technology in diverse fields including low power VLSI, embedded computing, communication hardware, and in general, the convergence of computing and communications. Other seminal work involves the determination of the relationship between indoor and outdoor gaseous particle counts [7]. The study included the areas of two household and one institutional buildings and indoor air-quality index of the environment was determined by monitoring gaseous pollutants over a period of twelve months. Time lags were prevalent in the particle counts between the indoor and outdoor environments of various houses. This insight was particularly useful for us in calibrating the data from our sensors and tuning it to control the purifier process.

Although not much is proposed to increase the quality and efficiency of household air purifiers at the time, there is a huge potential to incorporate the newest technologies to make their working ‘smart’ without incurring much cost, so as to make them easily available to the public. With the advent of latest electronic sensors and ever increasing computing power, the incentives are bigger than ever to pursue research in this area.

III. Data Monitoring and Collection

A. MQ2 Gas Sensor

The MQ2 sensor module is particularly utilized for gas leakage detection in multiple fields. It has the capability to identify LPG, i-butane, propane, methane, alcohol, hydrogen and smoke. A small heater combined with an electro-chemical sensing tool, are the main parts embedded in this device. The sensors in this series have the tendency for a range of gases and are specifically preferred for indoors at room temperature, thus highly relevant for our study. An analog signal is produced as an output that can be read with the corresponding input of the Arduino.

B. MQ7 Gas Sensor

MQ7 is a highly sensitive sensor suitable for sensing Carbon Monoxide concentrations (Parts Per Million (PPM)) in the environment. Usually, the MQ7 is preferred for measurement of concentrations ranging from 20 to 2000 ppm. In addition to high sensitivity, it has a fast response time, giving it’s output as an analog resistance. The drive circuit is very simple, just a voltage divider; which requires to power the heater coil with 5V DC or AC , and coupled with a load resistance, connect the output to an ADC or a simple Op-Amp comparator.

C. BMP180 Barometric Pressure Sensor

The BMP180 module is used particularly for its two tangible benefits for the measurement in small IoT systems – it gives significant precision and consumes a relatively low amount of power as compared to its competitors. The sensor can be utilized for a pressure range of 300 to 1100 hPa with an accuracy of 0.02 hPa in its highest resolution mode. Additionally, the module can be put into use with only 1.8V to 3.6V input voltage. When some outer circuit is connected with the sensor, the power range becomes 3.3V to 5V, which is generally acceptable.

D. DHT22

The DHT22 module is the one that contains the compound calibrated digital signal output of the temperature and humidity sensors. The sensor contains a sensor (capacitive), a little wet components and some ultra high-precision measurement devices which are suited to measure temperature, which combined together are connected with a high-performance 8-bit micro controller.

E. Rain Sensor and LDR

The rain sensor module is a handy tool for rain detection. It contains two coupling tools which are critical to its functioning

– the rain base and controller base. In addition, there is an electricity indicating bulb/LED and a potentiometer to control sensitivity. The extent of rain is determined by the quantity of drops from the analog output. When supplied with 5V electricity, the bulb turns on when the rain base has no drops, and DO output is high. When wet with a little quantity of drops, DO output turns low, and the detector turns on. On removing the rain droplets, and when brought back to the original state, outputs again turns high.

A photo resistor (or light-dependent resistor, LDR, or photo-conductive cell) is a light-determined fluctuating resistance. The resistance of a LDR goes down with when the incident light intensity increases marginally. LDR exhibits significantly big value of resistance when place in a damp environment, possibly in the range of mega-ohms (MΩ). In contrast, resistance drops to the range of hundreds when the device is placed in light.

IV. Data Verification

We collected the data from the sensors over a period of 40 hours in a typical household setting. Although due to the imperfections of the low-cost sensors, the data collected might be susceptible to noise, it was nevertheless quite near to the official readings collected by the weather monitoring center. The readings from the sensors give only the voltages and resistances values which are directly related to the corresponding particle density/light intensity of the gas/illumination that the sensor is designed to analyse.

We compared our real time recorded data from the sensors and the official values of AQI measured at a nearby site.

A. *Temperature verification*

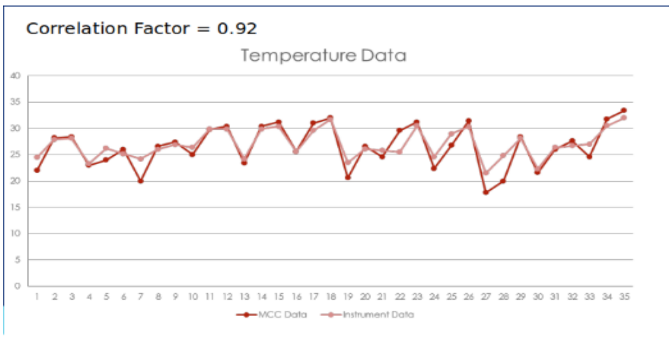

Fig. 3. Temperature comparison

B. *Pressure verification*

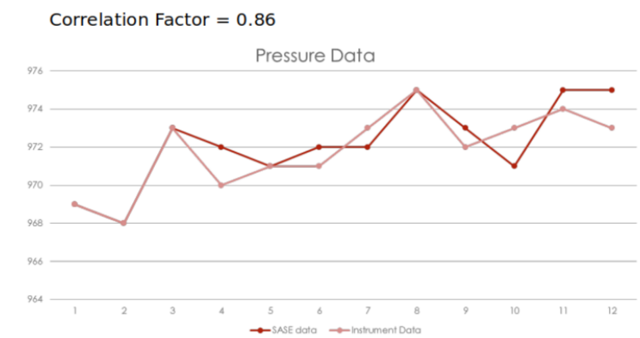

Fig. 4. Pressure comparison

C. *Humidity verification*

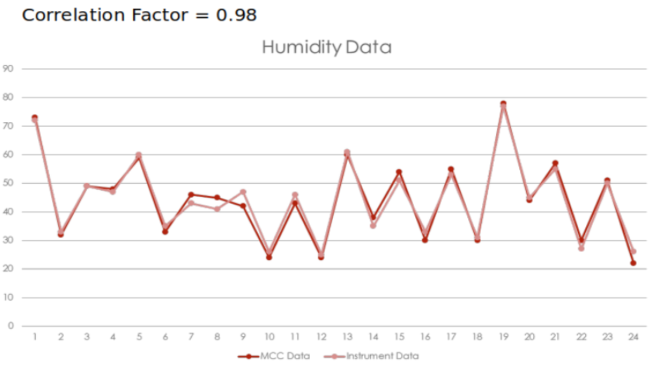

Fig. 5. Humidity comparison

The correlation factor (k) is determined by the following formula and indicates the similarity between the two datasets as it approaches to 1.

$$k = n(\Sigma xy)-(\Sigma x)(\Sigma y)/\sqrt{[n\Sigma x^2-(\Sigma x)^2][n\Sigma y^2-(\Sigma y)^2]} \quad \ldots(1)$$

We collected the official 24 hour data for temperature, pressure and humidity from a weather monitoring facility in Rohini, New Delhi and calculated the correlation factor with our recorded data from the sensors. All three data sets gave out correlation factors > 0.85, indicating that our readings are accurate and good to use further.

V. Controlling the Purifier process

The Pseudo code for the feedback control mechanism of the purifier is shown below. For simplicity, we have assumed that we are controlling a D.C. motor from only one parameter: the sum of the voltages (corresponding to respective pollutant particles) and resistance (corresponding to the solar irradiance).

```
For each cycle:
  take readings of all sensors via serial bus;
  segregate the voltage and resistance values from temperature, humidity,
            LDR  and rain warning values;
  calculate sum of the voltage and resistance values;
  define higher and lower threshold values of motor operation;
  define higher, mid and low motor speeds for motor;
  if sum > higher threshold:
    send high speed command to motor;
  if sum < higher threshold and sum > lower threshold:
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send mid-speed command to motor;

else:

send low speed command to motor;

A. On-line sensor readings

A table containing the collected voltage and resistance readings from our apparatus is shown below. Higher voltage and resistance readings correspond to higher concentrations of respective particles and irradiation in the surrounding.

TABLE I. SENSOR READINGS

Time Stamp (s)	Equivalent voltage/resistance readings		
	MQ2 (mV)	*MQ7 (mV)*	*LDR (resistance) (mΩ)*
1	121	732	343
2	143	701	341
3	140	701	341
4	132	710	345
5	130	707	340
6	144	718	339
7	142	718	339
8	142	720	468
9	150	721	472
10	151	726	465

For simplicity, here we have shown the motor control using only the resistance values from the LDR. The lower threshold is set at 200 milliohms and the higher threshold is set at 400 milliohms. In the below shown graph, the motor is running at the mid-speed (300 units) for the corresponding LDR readings. When the readings go past the higher threshold, high speed command (700 units) is sent to the motor.

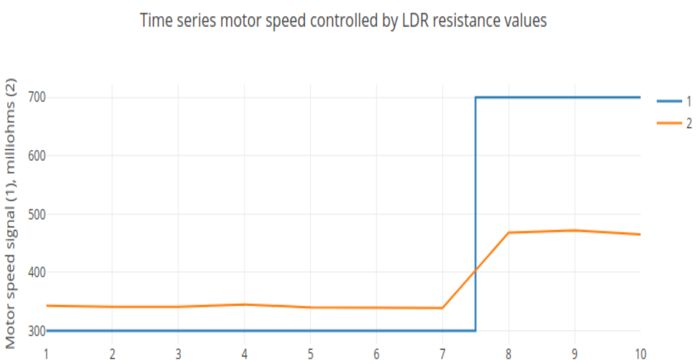

Fig. 6. Motor control through LDR sensor readings

Similarly, a sophisticated algorithm can be developed including the readings from all the sensors that can be fed to the control mechanism of the air purifier. The contribution of each pollutant to the quality of air has to be analyzed before designing such an algorithm.

Conclusion and Future Scope

This paper presented an approach to develop an outdoor/indoor air quality and weather monitoring system that records and monitors air pollutants and weather parameters, and simultaneously incorporate that into making closed-loop air purifiers. In this way, manual control of purifiers can be made unnecessary and they can be made “smart” by automatically determining the operating intensity by sensing the surrounding air quality.

Further challenges include other factors like traffic and daylight for prediction of air quality and subsequent controlling of air purifiers. Also, the whole system can be made wireless and users can track the on-line status of system through GSM module. In addition to it, long time (> 7days) weather forecasting by using Machine Learning and covering larger area can be done before rolling out this product for commercial purposes. Furthermore, the operation for the whole product can be made self sufficient by incorporating solar cells to power the sensors. Another use that can be harnessed by the meticulous observation of the data collected from the sensors. Anomalies in observed data can be used to identify possible abrupt changes in the environment and further used to precipitate quick response to the situation.

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